HIGH QUALITY WIRE ROD AND BAR PRODUCTION AT YONGXING SPECIAL STAINLESS STEEL*

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Abstract
A new combination bar, bar in coil and wire rod mill has recently been commissioned at YongXing Special Stainless Steel Co. Ltd. In Huzhou City, China. The mill is designed to produce 250,000 tons per year of stainless valve steels, nickel-based alloy steel and numerous stainless grades, including austenitic, ferritic, dual phase and hardening steels. The new rolling mill, supplied by Primetals Technologies, has capabilities for rolling wire rod in sizes 4.5 – 16.0 mm, bar in coil from 16 – 40 mm and straight bar from 30 – 130 mm. The equipment includes quenching and heat treatment facilities to maximize in-line processing, plus new innovations such as stepless coil reforming for wire rod and optical bar counting for straight bar products, all selected to deliver higher grade stainless products. As production in the new mill continues to increase, YongXing is able to meet demands of customers seeking special grades for applications in the nuclear, automotive and petrochemical industries, among others, affirming their position as a top stainless steel supplier in China.This paper presents several equipment and process innovations incorporated into the new mill design and examines the initial results.

Keywords: Wire Rod; Bar in Coil; Bar; Stainless Steels; Productivity.

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** Technicalcontributionto the55º Seminário de Laminação e Conformação de Metais,part of the ABM Week, October 2nd-4th, 2018, São Paulo, SP, Brazil.*

1 INTRODUCTION

YongXing Special Stainless Steel Co., Ltd (referred to as YongXing) specializes in the development and production of special stainless steel rod and wire, mainly used in petrochemical, basic energy, equipment manufacturing and other industrial fields. As a leading enterprise of stainless steel rod and wire in China, it plays an important role in the development of the nation's basic industries.

The recent evolution in the industry has also led to a severe lack of skilled/experienced workers. The previous generation of workers could rely on their experience to optimize aging equipment and process practices. Now, the key to success in sustaining/improving operations is to replace outdated equipment with new technology and increase the level of automation in a new facility. The installation of a modern mill can provide consistent operations with higher speeds, less maintenance and downtime, and longer wear part life for more up time between changes, and as little operator intervention as possible.

2 MATERIAL AND METHODS

2.1 Products and Processing

YongXing produces wire rod and bar products for applications in nuclear and petrochemical industries, among others. Grades rolled in the combination mill are principally various stainless steels and nickel-based alloys. The stainless steels include austenitic, ferritic, martensitic, welding, vulcanized, dual phase and hardening grades, plus austenitic and martensitic stainless valve steels.

YongXing rolls a wide range of sizes to satisfy the specialty steel market – wire rod from 4.5 – 16.0 mm, bar in coil from 16.0 – 40.0 mm and straight bar from 30.0 – 130.0 mm. The wire rod is formed into coils with an outer diameter of 1,250 mm and an inner diameter of 850 – 900 mm. The bar in coil package has an outer diameter of 1,250 mm and an inner diameter of 850 mm. Straight bar bundles are made in lengths from 6 – 12 m.

Starting billets for the stainless steel grades are either 220 mm, 180 mm or 150 mm square, from 6 - 7 m in length and weights from 1,200 – 1,800 kg. The nickel-based alloy billets are 120 mm round, with a length of 7 m and weight of 612 kg.

The mills are designed to roll at a maximum speed of 80 m/s with production rates up to 62 t/h. Yearly production for the new mill is expected to be approximately 250,000 t.

2.2 Rolling Mill Equipment

A significant amount of equipment was provided to YongXing for the new mill, including a new reversing breakdown mill and a 3-roll sizing blockin the main roughing and intermediate mill trains.

The straight bar line included a cooling bed run-in table with brake slide, cooling bed, plus bar handling with hot saws and bar counting. Automated bar bundling and binding prepare the finished bar for storage and shipment.

The wire rod line equipment included a 680 shear, a 10-stand Morgan Vee No-Twist® Mill, 4-stand Morgan Reducing/Sizing Mill, Morgan Water Boxes, Morgan Intelligent

Pinch Roll and Morgan High Speed Laying Head. For controlled cooling of the coiled rod, a 4-zone Morgan Stelmor® Conveyor was installed, ahead of a new stepless coil reforming station.

The bar in coil line was configured with pouring reels and coil quenching tanks for heat treatment of the coiled product. Coil handling of both bar in coil and wire rod coils was combined in a common system with vertical stem pallets and a vertical coil compactor.

Figure 1 below shows the overall layout of the rolling mill.

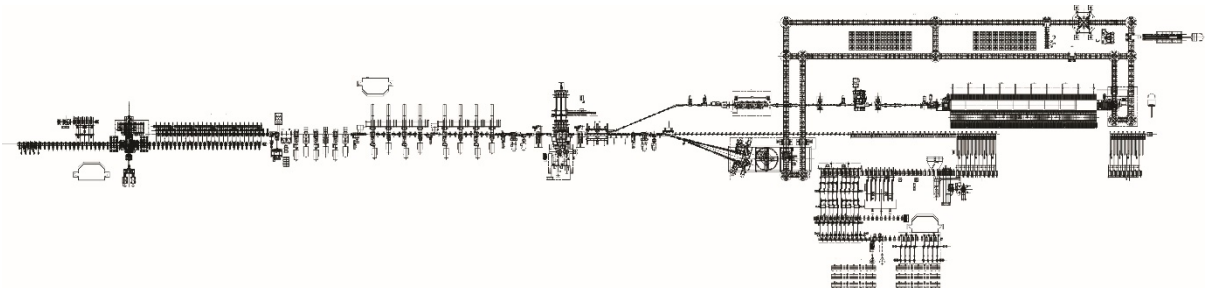

Figure 1 – Mill layout

2.2.1 Bar Line

Mill

The breakdown mill is a housing-less reversing sliding stand, with RedRing® design (see Figure 2). Grooves are changed according to pass design by sliding the stand transversally to the rolling line, which remains fixed. Between subsequent passes, rotating devices turn the bar under rolling. The sliding breakdown has a 940 mm maximum roll centerline distance and a 1,800 mm roll barrel length.

Figure 2 – Reversing sliding breakdown with bar rotating device

The roughing, intermediate and pre-finishing trains are all composed with fifth-generation RedRing stands, scaled in three sizes, with maximum roll openings variable from 450 to 750 mm.

Cooling Bed

For the bar line at YongXing, a shear arrangement is used to cut the bars headed to the cooling bed. In order to cover the complete size and speed range, a 1,400 mm dual ratio crop and divide shear with 600 mm chopping shear is used for dividing sizes ≤ 60 mm. For sizes greater than 60 mm, no divide cuts are necessary due to the length of the cooling bed. The cut lengths to the cooling bed are calculated based on multiples of the finished commercial cut length. The cut length optimization software adjusts the primary cut lengths to the cooling bed to minimize yield losses. The tail end of the last bar can be cobble cut at the divide shear arrangement, or if the length is greater than 3 m, collected at the short bar recovery after the abrasive saws.

Figure 3 – Brake Slide to Cooling Bed

Immediately after the divide shear arrangements are the approach and run-in tables to the cooling bed. The approach table is provided with individually driven horizontal rollers that are gradually inclined to match the incline of the run-in roller table. The approach table is designed to operate faster than the finishing stock speed in order to create a gap between divided bars prior to entering the brake slide to the cooling bed.

The run-in table rollers are also individually driven and inclined at the same angle as the brake slide. The brake slide, as shown in Figure 3, lifts the bar off the run-in table rollers to allow braking of the bar under friction before being discharged onto the first notch of the cooling bed. A hydraulic cylinder cushions the bar against the brake slides while lowering it for a smoother control. The entry section of the run-in table is equipped with drop down walls to prevent the larger bar from sliding down the brake slide before the previous bar is discharged. The number of drop down walls used depends on the product size. Special wear-resistant plates along the approach table and brake slide prevent scratching of the bars prior to the lifting of the brake slide.

For conventional operation at YongXing, the bars are deposited from the brake slide onto the straightening grid of the cooling bed. Moving rakes, operating automatically by two variable speed motors, advance the bars one notch at a time from the straightening grids to the fixed rakes. The speed of the rake section can be varied to control the temperature of the product exiting the cooling bed. A set of aligning rollers are located at the end of the rake section to align the front of bars in layers before cutting at the cold saw for better yield.

During normal operation, the bars are cooled on the moving rakes and then discharged one by one, onto a grouping chain transfer, driven electromechanically, which shifts layers of bars in required numbers. A lifting tray system picks up each layer of bars and moves them onto the cooling bed run-out roller table feeding the cold saws.

Fast transfer across the cooling bed is also provided to deliver products to the slow cooling bins at elevated temperatures. In this case, the lifting tray system picks up the layer of bars immediately after they have been deposited on the moving rakes after the straightening grid and quickly transfers them to the cooling bed run-out table for cutting the final commercial lengths, before depositing them into the slow cooling bins.

Sawing Systems

Dividing the finished product at YongXing for handling and shipping requires a high-quality cut to prevent product surface cracks or undesirable hardening effects.

As installed at YongXing, the EVO abrasive disc saws, Figure 4, enable cutting several different sizes, shapes and grades with the same machine, improving operational flexibility. This high-speed, fully automated process allows full production capability of the plant. Both hot and cold materials may be processed and all the cutting parameters are system-controlled, including sample cuts and removal.

Figure 4 – EVO Abrasive Disc Saw

Bar Counting

The patent-pending bar counting system at the entry to the bar bundling area at YongXing provides the accurate piece count of the bars as they are transported to the stacker. The autonomous system consists of illumination of the ends of groups of bars as they pass on the conveyor, an image processing camera, and ancillary components. As bars pass the camera, the images of the bar ends are digitally captured and the image is processed with a proprietary algorithm to provide the number of pieces in the layer. The system provides an accurate and reliable means of providing a count for each of the bar bundles.

Bar Bundling and Binding

The bundle-forming station at YongXing includes three independently driven chain sections. The first is a buffer chain section accumulating bars that cannot be advanced to the next section. The second section pre-selects a fixed number of bars for feeding into the bundle-forming cradle. The third section feeds the bars to the bundle-forming cradle. The cradle lowers incrementally, minimizing the drop distance from the lances to the top of the bundle. Vertical and horizontal rollers then help support the loose bundle during transfer to the tying machines.

Two sets of fixed bundle-forming arms and tying machines are provided at the exit of the bundle-forming station. The loose bundle advances through the tying machines and stops at a pre-set position depending on the commercial length to space the ties equally along the length. The bundle-forming arms compact the bars into a bundle before the ties are applied. After tying, the bundle-forming arms retract and the bundle advances to the next tying position. Figure 5 shows the bundle-forming station arrangement.

Figure 5 - Bundling Station & Tying Machines

2.2.2 Wire Rod

Shears

A 680 mm continuously rotating divide shear arrangement, preceded by a pinch roll unit, was installed at YongXingahead of the finishing block. This shear arrangement is used for front and tail end crop cuts which are collected in scrap buckets below mill floor level. In case of production interruptions downstream, the shear makes a divide cut and chops the bar.

Vee No-Twist Mill

The modular and versatile design features of the Vee No-Twist Mill allow the mill to be supplied in 4-, 6-, 8- or 10-stand configurations with fixed single pass reductions from 10 to 25%, allowing a wide range of grades to be rolled.

The Vee No-Twist Mill, Figure 6, can be configured with 250 mm, 230 mm or 160 mm cantilevered roll housings, depending on the processing requirements and product size range. Due to the unique design of the pinion and bevel gear housings, the roll housings are interchangeable, allowing the mill configuration to be changed to increase the mill's product size range (5.0 mm to 26.0 mm) or enhance the processing requirements, depending on the future demands of the world market. For this application, a 10-stand 16 % average reduction Vee No-Twist Mill was installed with a 230 mm ultra heavy-duty (UHD) roll housing providing the optimum configuration for the size range specified as well as reduced roll cost and improved section control.

Figure 6 – Morgan Vee No-Twist Mill

Reducing/Sizing Mills

One of the most significant advancements in high speed rod mills was the development of the patented Morgan Reducing/Sizing Mill (RSM) in the early 1990's, which serves as a post-finishing mill block. More than 70 strands of RSMs have been installed worldwide, mostly as part of new mills and major mill modernization projects.

Figure 7 – Morgan Reducing/Sizing Mill

At YongXing, a two family rolling method is used in conjunction with the 16% average reduction No-Twist Mill to restrict the overall reduction of the special stainless and nickel alloy products. With the installation of the 3-roll sizing, a single roll groove setup is used in each stand, from the first stand in the roughing mill to the last stand in the finishing mill, to produce the necessary feed sections to the rod outlet. This not only simplifies the mill setup, but also improves yield through reduced number of cobbles and elimination of trial bars. It also significantly reduces the roll and guide changes, and therefore the need to maintain their inventory. The mill's design provides for future off-line roll units and the quick-change transfer car to allow size changes to be made within five minutes. As a result, even when the rolling rate or finishing speed has not been significantly increased, the mill is still capable of improving its productivity through increased operating efficiency with the reduction in downtime for roll changes.

The RSM also provides improved product tolerance and ovality – typically ±0.1 mm tolerance and 0.12 mm ovality. With special steel products, the ability to produce a close-tolerance product reduces the amount of peeling required, resulting in large savings during post-rolling operations.

In addition, experience with the oval-round-round-round pass sequence in many mills has shown that the overall pass life is double that of conventional rolling, thereby reducing the downtime for pass changes. This pass sequence is also beneficial to wire drawers and other post-rollers, since it minimizes circumferential surface variations at the parting areas.

Water Boxes

A common limitation in rod and bar mills is the control of product temperature through the process line. In many cases, there is a lack of cooling capacity, making difficult the control of mechanical and metallurgical properties, as well as amount and type of scale. Product quality requirements, particularly for specialty grades like those produced atYongXing, have therefore driven many mills to install latest technology water box systems that offer efficient cooling with components that are

easytomaintain.ThePrimetals Technologies split bore cooling nozzle design allows operators to quickly and easily open a nozzle for inspection or cleaning.

Pinch Roll and Laying Head

An area of the process line that commonly limits the success of a rod mill is that of the laying head and pinch roll. The ability to roll small size product at high speeds is meaningless if the ring pattern on the Stelmor® cooling conveyor is not consistent and the laying head pipe needs frequent changes. A bad ring pattern can result in failure to achieve the specified tensile uniformities and additional personnel required at the laying head or reform station to prevent cobbles in each coil. The Morgan High Speed Laying Head was developed to operate at those speeds and has achieved a good reputation for reliable high-speed operation. Numerous mills have upgraded their laying head and pinch roll systems in recent years to increase production, reduce manpower, improve yield and ensure consistent product quality.

Recent developments on the high-speed laying head system have resulted in a new upgrade package, which YongXing included in its new mill. Design changes in the laying head and pipe support have led to even better performance at high speeds, with extremely low vibration levels. Also, a significant advancement in the technology of the laying head pipe, the patented SR Series® pipe, now enables the rolling of many, many more tons of small diameter products at high speeds – resulting in a dramatic reduction in downtime for pipe changes.

The success of the laying head and pinch roll system is also dependent on the mechatronics package that is integral to an equipment upgrade. This system provides for consistent coordination of speeds between the units, for repeatable front end positioning of each coil, fine control of ring diameter and wobble adjustment for large sizes. The Morgan Intelligent Pinch Roll incorporates servo control of pinch force and position, closed loop control of pinch force and speed, plus rapid and repeatable roll close times.

Figure 8 – Morgan High Speed Laying Head and Pinch Roll

Stelmor Conveyor

The Stelmor controlled cooling system incorporates a wide range of processing conditions, including both fast and slow or hybrid fast and slow cooling in a single system to produce a wide spectrum of plain carbon, alloys, and stainless steel grades. This flexibility, coupled with controlled temperature rolling, allows more grades to be produced in a directly useable condition, thus eliminating or accelerating downstream processes such as recrystallization and solution treatment.

For slow cooling, the Stelmor is equipped with insulated covers which can be closed to retard the cooling rate. Solid conveyor rollers on the conveyor deck are designed to dissipate heat transferred from the rings during slow cooling, thus preventing distortion and reducing maintenance requirements. For YongXing, this operating mode is specifically used for martensitic stainless steels that will be heat treated off-line.

Immediately after the entry section is a curved traversing zone that directs product to either the Stelmor conveyor or Direct Solution Treatment (DST) line (Figure 9). This is used for direct charging of the coils on the conveyor into the solution treatment furnace for annealing/slow cooling through isothermal transformation of stainless steel grades.

Figure 9 - Stelmor and DST Lines

Coil Reform

The coil reform station is a critical element of the finishing end of the wire rod mill, collecting the rings from the Stelmor conveyor and DST line into an ideal coil package, while minimizing cycle time in order to meet production demands. Accurate control of coil plates and nose cone supports insures smooth and continuous coil collection. Integral to the reform tub is the ring distributor system, with a specially

designed rotating blade to guide the rings as they fall, creating a well-ordered coil package.

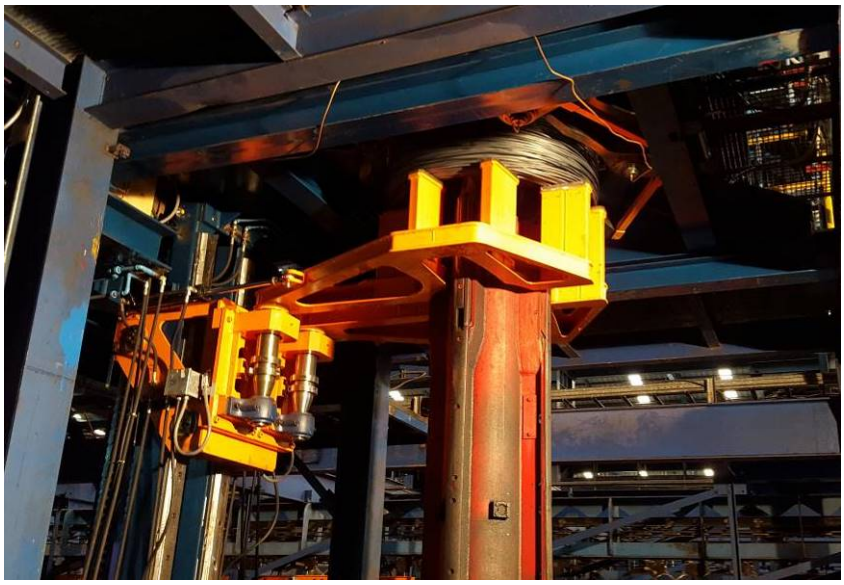

Figure 10 – Stepless Reform Station

At YongXing, the new, patented stepless reform station replaces the conventional long tub assembly that had fixed position iris fingers. In the new design, a dual coil plate arrangement supports the forming coil with independent drives for each. The two coil plates maintain a constant distance from the bottom of the ring distributor to the top of the forming coil during the forming cycle, eliminating the conventional system's crop between iris fingers and coil plate.

2.2.3Bar In Coil

Pouring Reels

A high-speed pouring reel switch located immediately before the rollerized turndown into the pouring reels at YongXing directs alternating bars within the billet gap into the individual pouring reels, providing sufficient time to transfer the coils from the reels onto the walking beam cooling conveyor. The turndown utilizes three cluster rollers to prevent scratching of the bar on the bar as it enters the pouring reels. These roller clusters are water cooled and air/oil lubricated for long life and reduced maintenance.

Two pinch rolls are located close to the pouring reels for control of tail ends as they enter the reel. All pinch rolls are traversable to allow quick change between the grooves required to cover the complete size range and include hydraulic roll mounting.

The pouring reels are equipped with wear strips on the outer rotating drum to prevent mechanical damage during the formation of the coil. An elevating coil plate assembly incorporated in the reel removes the coil from the tub.

A coil transfer mast transports the coils from either of the two pouring reels and delivers them directly to either water quenching tanks or the vertical pallet system (Figure 11).

Figure 11 - Pouring Reel Outlet with Water Quenching Tanks

2.2.4 Coil Handling and Compacting

A common vertical pallet coil handling system is being used to transport both the wire rod from the Stelmor or Direct Solution Treatment lines and bar in coil products to either the slow cooling pits or unloading station for internal transportation to off-line annealing and pickling facilities. The vertical pallet system has been designed with the flexibility to ensure the shortest transport time to allow the coils to be delivered to the slow coolingpits as quickly as possible, while also providing sufficient cooling distance to ensure low coil temperatures prior to trimming and compacting.

Figure 12 – Vertical pallet coil handling system

3 RESULTS AND DISCUSSION

3.1 Production Experience

The newly expanded combination wire rod, bar in coil and bar mill in Huzhou has been installed and has begun production.

The wire rod and bar mills are ramping up their production with a focus on the commercial austenitic stainless steel grades such as 201Cu, 204Cu, 303Cu, 304DC, 304H, 304HC (1,2 & 3), 304L, 304S, 316 and 316L. Harder stainless grades such as ER2209, ER 309LSI and Nickel Alloys will begin their initial testing in the upcoming months.

The contracted mill production rates and finishing speeds have been achieved on grades rolled to date with a maximum finishing speed of 80 m/s and rolling rate of 62 t/h for all rod sizes and bar in coil sizes < 40.0 mm.

Very good product tolerance has been achieved on all rod and bar products, with all rod products achieving the guaranteed tolerance of ± 0.1 mm with an ovality ≤ 0.12 mm. For many sizes these performance parameters have been exceeded (Figure 13). The only rod product size remaining to be rolled is 4.5 mm.

A major focus of the mill performance is related to surface defects. Many improvements have been made to reduce the defect depth especially on the rod and bar in coil lines. Surface defect depths of 0.04 mm are being achieved consistently on rod sizes ≤ 8.0 mm and between 0.04 to 0.08 mm on rod sizes > 8.0 mm. Bar in coil product surface defect depths are typically 0.08 to 1.0 mm; however, additional testing on reducing these depths to levels consistently < 0.08 mm are currently underway.

Figure 13 – Finished Product Tolerances

From a metallurgical properties standpoint, the mill has been able to meet or exceed the performance parameters for the grades and sizes rolled to date. The following table outlines a comparison between the on-line and traditional off-line heat treatment processing routes for both rod and bar in coil products.

Wire Rod Products						
Grade	Size [mm]	Property		Stelmor	Direct Solution Treatment	Off-line Treatment
304HC	7.5	Mechanical Property	TensileRm(MPa)	578	519	513
			Elongation A(%)	56	64	67
			Reduction Z(%)	80	82	83
		Grain Size (ASTM No.)		9.5 - 10	4.5 - 6	3.5 – 5 Partial 1.5 – 2.5
304HC1	7.5	Mechanical Property	TensileRm(MPa)	588	529	525
			Elongation A(%)	58	68	70.4
			Reduction Z(%)	80	83	81.8
		Grain Size (ASTM No.)		9.5 - 10	4.5 - 6	3.5 – 5 Partial 1.5 – 2.5
304HC3	7.5	Mechanical Property	Tensile Rm(MPa)	572	511	505
			Elongation A(%)	54	61	62
			Reduction Z(%)	79	82	81
		Grain Size (ASTM No.)		9.5 - 10	4.5 - 6	3.5 – 5 Partial 1.5 – 2.5

Grade	Size [mm]	Property		Water Quench	Off-line Treatment
304D	18.0	Mechanical Property	Tensile Rm(MPa)	582	554
			Elongation A(%)	58	58
			Reduction Z(%)	78	77
		Grain Size (ASTM No.)		8 - 9	2.5 – 4.5
304HC	16.0	Mechanical Property	Tensile Rm(MPa)	560	503
			Elongation A(%)	53	55
			Reduction Z(%)	78	80
		Grain Size (ASTM No.)		8 - 9	3.6 – 6
304D	16.0	Mechanical Property	Tensile Rm(MPa)	580	542
			Elongation A(%)	59	60
			Reduction Z(%)	79	79
		Grain Size (ASTM No.)		8 – 9.5	2 – 4.5

3.2 Customer Response

Improved dimensional tolerance and surface quality has provided yield savings to the downstream processing lines due to reduced peeling after pickling.

Production of rod sizes ≤ 5.5 mm has reduced the downstream wire drawing cost to produce fine wire.

Based on the above product tests, the material quality is more uniform with respect to grain size through the on-line heat treatment process route compared with off-line. This has already met the higher material property requirements for spring wire and valve steel grades. In addition, the on-line heat treatment cost is less than 50% of the traditional off-line heat treatment cost.

4 CONCLUSION

The mill has successfully demonstrated the ability to produce high-quality stainless steel products with superior dimensional tolerance, surface quality and mechanical properties. This, coupled with high operating flexibility, allows the mill to support short delivery cycles while maintaining a high operating efficiency by minimizing downtime due to reduced family rolling and quick-change capabilities. Increased productivity and reduced conversion cost through in-line heat treatment puts YongXing Special Steel in a dominant and unique position in the Chinese market.

With the continuing focus on rolling harder stainless grades with enhanced properties, the new mill will allow YongXing Special Steel to better service and expand their existing customer base within China and the export market to Europe and the United States.